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Results of vortex tube usage in diesel exhaust gas recirculation system

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Abstract

The article outlines the results of vortex tube usage in exhaust gas recirculation system of diesel 4ЧН13/15. It presents main functional features of a vortex tube. It is shown that the usage of the tube allows reducing the temperature of recirculated gas up to 60 °C and significantly diminishes the content of nitrogen oxide and particulate matter in exhaust gases of an engine at general operation modes, conforming to the Rule of Economic Commission for Europe Organization of United Nations #96.

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Keywords: Diesel, exhaust gas, noxious substances, toxicity, vortex tube, temperature.

1. The research of vortex tube usage in exhaust gas recirculation system

In virtue of some diesels working processes peculiarities actions, aimed at wastes diminution of unburnt combustibles, carbon oxide, hydrocarbon and harmful particles are accompanied by the growth of nitrogen oxide emissions and vice versa. Then to provide an appropriate diesel work in accordance with functioning and long-term standards of toxicity, there is an urge to use methods of reduction of noxious substances, including the combination of exhaust gas recirculation system with cooling of recirculated gas and exhausted gas aftertreatment [1].

It is worth mentioning that the creation of a reliable and effective heat transfer device for recirculated gas cooling is a challenge due to the stratum and pollutants, extracted from exhausted gas of diesel.

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From this perspective the vortex tube is of considerable interest, which can be used for cooling the recirculated gas [2,3]. Vortex tubes, presenting the devices where Ranque-Hilsch Effect takes place, allow to divide the stream of compressed liquid (dripping and elastic) in 2 constituents: cold and warm, widely used in different spheres of engineering [4]. These are simple, reliable and cheap devices, with no nonferrous metal in it (as common regenerative heat-exchange units), featuring insignificant water resistances, demanding simple maintenance.

An important feature of applying vortex tube in exhaust system is both cooling of recirculated gas and provision of comfort temperature of exhaust gas on the input in oxidation catalyst to provide an efficient operation at all diesel functioning modes.

The article presents the results of experimental estimate of usage of vortex tube to increase the efficiency of exhaust gas recirculation system on the diesel 4ЧН13/15.

Experimental assembly. System diagram of exhaust gas recirculation and after treatment with placement locations of sensors (Fig. 1).

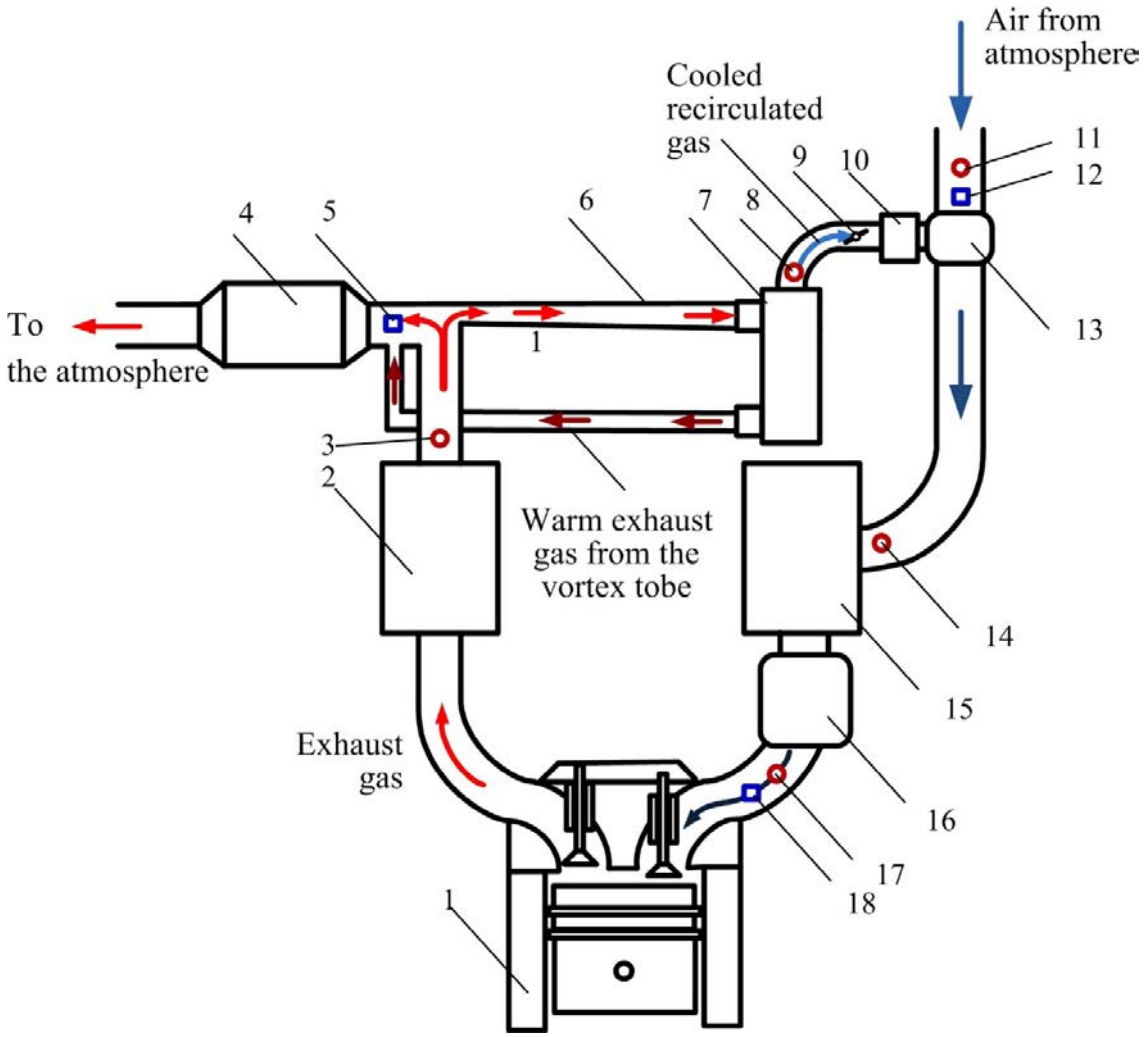

Fig. 1. System diagram of exhaust gases recirculation and after treatment:
1 – diesel; 2 – gas turbine; 3, 8, 11, 17 – temperature sensing points; 4 – oxidation catalyst, 5, 12, 18 – pressure sensing point; 6 – exhaust gases feeder to vortex tube; 7 – vortex tube; 9 – clapper, controlling the volume of recirculated gas; 10 – consumption indicator; 13 – gas converter; 15 – compressor, 16 – charge air cooler.

General engineering characteristics of vortex tube, optimized for operating conditions in exhaust gas recirculation system diesel 4ЧН13/15, as follows in Table 1, Fig. 2 displays its circuit diagram and physical form.

Table 1. General engineering characteristics of vortex tube

Engineering characteristics	*Unit of measurement*	*Parameters*
Body length of vortex tube	м	0,5
Body bore of expiratory fitting of cooled exhaust gas flow	м	0,037
Overall opening diameter of port for air flow of warmed exhausted gas	м	0,1
Port bore for air flow of warmed exhaust gases, in case of temperature drop up to 60 K	м	0,097
Area of exhaust gas inlet fitting in vortex	$м^2$	$0{,}11 \cdot 10^{-2}$
Restriction of body bore diameter	degree	7

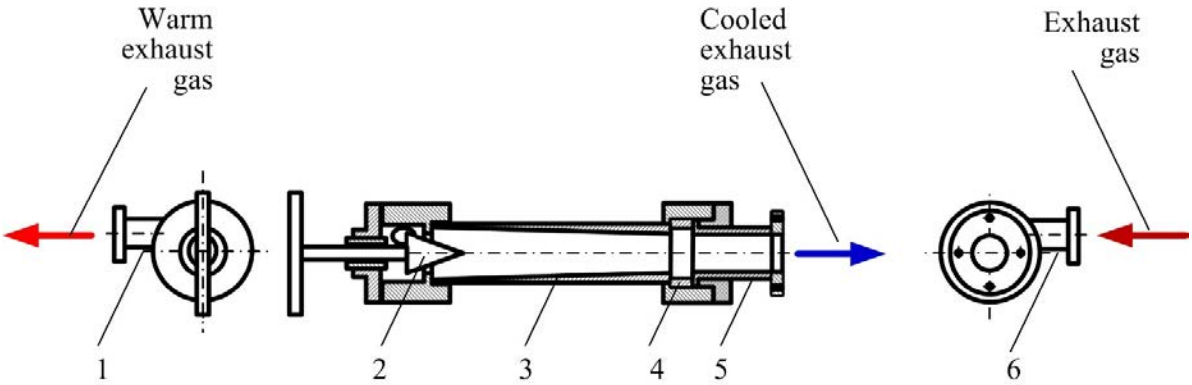

Fig. 2. Vortex tube,

a – circuit diagram of the vortex tube: (1 – expiratory fitting of air flow of warmed exhaust gas; 2 – throttle flap; 3 – body; 4 – vortex; 5 – expiratory fitting of cooled exhaust gas flow; 6 –inlet fitting of exhaust gas in vortex); b –physical form.

Exhaust gas recirculation system with the vortex tube provides the ability to control the volume flow of recirculated gases within the range not less than 0-20% from the volume flow of inlet charge and maximum temperature fall of recirculated gas at 60K relatively the temperature of exhaust gas, penetrating into the vortex tube.

2. Experimental results of the implementation of cooling of recirculated gas.

During the experimental research of emissions release of diesel 4ЧН13/15 with their recirculation and cooling, we started out from toxicity index of particulate matter being twice higher than nitrogen oxide, 10 times higher than carbon hydride, and 20 times than carbon oxide [5], aggressivity coefficient of nitrogen oxide (49) and particulate matter (41,5) surmount greatly the aggressivity indexes of carbon hydride (1,26 and 1,0 relatively) [6]. Taking into account the above mentioned data and the circumstance that the pilot experiments proved that carbon oxide and carbon hydride content in diesel 4ЧН13/15 exhaust gases is much lower of the standardized values, in further research works we restricted to the estimation of particulate matter and nitrogen oxide exhaust.

In determining of the influence of exhaust gas recirculation system functioning on the content in exhaust gas diesel 4ЧН 13/15 of particulate matter and nitrogen oxide, we also estimated the quantity contribution and temperature of recirculated gas during its general modes operation, corresponding to the Rule of Economic Commission for Europe Organization of United Nations #96

Implementation of cooling of recirculated gas naturally leads to certain temperature fall of incoming charge on the input to cylinder barrels, resulting in content fall in exhaust gases of nitrogen oxide (by means of temperature fall of working body in cylinder), and particulate matter (taking into account density of incoming charge, penetrated into the cylinder, consequently boosting coefficient of excess air). (Table 2)

Table 2. The content of nitrogen oxide and particulate matters in exhaust gases of diesel 4ЧН13/15 during its general modes operation, corresponding to the Rule of Economic Commission for Europe Organization of United Nations #96 *(share of recirculated gases is 18%; cooling of recirculated gas up to 60 °C).*

Mode		*Content NO_x [ppm]*			*Content PM [g/m]*		
		Originall	*Recirculation added*	*Recirculation and cooling added*	*Original*	*Recirculation added*	*Recirculation and cooling added*
n = 1850, min^{-1}	Load 100 [%]	250,2	75,5	71,7	39,1	51,9	51,5
	Load 75 [%]	149,8	50,1	44,3	17,5	32,3	31,1
	Load 50 [%]	121,1	18,0	14,6	5,6	13,8	10,5
n = 1250, min^{-1}	Load 100 [%]	712,4	190,1	173,8	139,4	142,4	139,1
	Load 75 [%]	370,8	100,7	88,8	111,0	119,1	114,8
	Load 50 [%]	38,2	10,4	8,7	40,3	49,5	45,3

The data from the table depict, that the organization of exhaust gas recirculation appeared to influence positively on reduction of content in exhaust gas of nitrogen oxide, however it led to some growth of the general flow of particulate matter. Implementation of recirculated gas cooling provided NOx abatement and some decrease of particulate matter emissions, quantitative concept is illustrated in the Table 3.

Table 3. The content of nitrogen oxide and particulate matters in exhaust gas of diesel 4ЧН13/15 by means of cooling of recirculated gas at 60 °C during its general modes operation, corresponding to the Rule of Economic Commission for Europe Organization of United Nations #96 [%]

Mode					
n = 1850 min-1			*n = 1250 min-1*		
Load 100 [%]	Load 75 [%]	Load 50 [%]	Load 100 [%]	Load75 [%]	Load 50 [%]
Nitrogen Oxide					
5,1	11,6	18	8,5	11,8	16,3
Particulate matter					
0,08	3,7	16,3	2,3	3,6	8,5

Results of the conducted work witness of the possibility and reasonability of using heat pipes in exhaust gas recirculation system. Thus appliance of the vortex tube in this system in diesel 4ЧН13/15 in case of temperature reduction of recirculated gas at 60 °C with their share in incoming charge 18 % allowed to low nitrogen oxide and particulate matter emissions on the modes, typical for road building machines (75 % load) at 11.6 and 3.7 % relatively.

Going further, authors aim to estimate the positive influence of incoming charge cooling by using vortex tube with exhaust gas recirculation at effective fuel rate and possibility to provide an optimal temperature of exhaust gas on the input to oxidation catalyst for its effective functioning during different operation modes of an engine.

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